



Operating Mode Emissions Estimation Methodology Development and Application

FINAL REPORT

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**Task 5.2 Final Report - Operating Mode Emissions Estimation
Methodology Development and Application**

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EXECUTIVE SUMMARY

The Texas A&M Transportation Institute (TTI) prepared this report to describe the development and use of a method needed to disaggregate on-road mobile source evaporative process emissions of existing emissions inventories (EIs) into operating mode components, using the United States Environmental Protection Agency's (EPA) Motor Vehicle Emissions Simulator (MOVES) model. This work, sponsored by the Texas Commission on Environmental Quality (TCEQ), was required primarily due to limitations of the MOVES model, to help support the Dallas Fort-Worth (DFW) and Houston-Galveston-Brazoria (HGB) state implementation plan (SIP) revision for the 2008 eight-hour ozone National Ambient Air Quality Standard (NAAQS), under the U.S. Clean Air Act (CAA).

For the DFW and HGB SIP revision, TCEQ will need to demonstrate that any growth in emissions, from the base year to the attainment year, that are the result of growth in vehicle miles traveled (VMT), will be offset. The "VMT offset demonstration" is the required analysis that shows whether there are any emissions that must be offset.¹ Four EIs are required for each area's VMT offset demonstration, as defined in Table 1.² These existing EIs, however, reflect total on-road mobile source emissions, which include diurnal, or "cold soak", operating mode evaporative emissions that are unrelated to VMT or trips. Evaporative emissions during vehicle cold soaks result from diurnal temperature effects on fuel systems of non-operating, cooled down vehicles (i.e., cold soaking vehicles), not from vehicles during travel (running, or, operating) or hot vehicles at trip ends (hot soaks). Cold soak emissions therefore can be excluded from the VMT offset demonstration EIs.³

¹ The VMT offset demonstration (VOSD) is to show that, from the base year to the attainment year, projected growth in VMT will not hinder the nonattainment area's progress toward attainment of the EPA's 2008 eight-hour ozone standard. The EPA's VOSD guidance is available at this link:

[EPA VMToffset guide](#)

² TTI and the North Central Texas Council of Governments (NCTCOG) employed standard TDM link-based EI methods to develop the four MOVES county scale EIs. The EI development reports are: *Houston-Galveston-Brazoria (HGB) 2008-Eight-Hour Ozone Reasonable Further Progress (RFP) On-Road Mobile Emissions Inventories* (TTI, June 2021); *Houston-Galveston-Brazoria (HGB) On-Road Mobile Vehicle Miles Traveled (VMT) Offset Emissions Inventories* (TTI, October 2021); *Dallas-Fort Worth Motor Vehicle Emissions Simulator 3 (MOVES3)-Based Reasonable Further Progress On-Road Emissions Inventories and Control Strategies Reductions for Analysis Years 2011, 2017, 2018, 2020, 2023, 2026, and 2027* (NCTCOG, August 2021); *Dallas-Fort Worth (DFW) On-Road Mobile Vehicle Miles Traveled (VMT) Offset Emissions Inventories* (NCTCOG, October 2021).

³ Limiting VOSD analyses to emissions only related to VMT or vehicle trips by excluding cold soak evaporative emissions is used by California as detailed in the report at this link: [CARB report](#)

Table 1. DFW and HGB VMT Offset Emissions Inventory Descriptions.

VMT Offset EI Scenario	Activity Input	Emission Rates Input ¹	EI Source ²
2011 Base Year	2011 (Base Year)	2011 Control Strategy	TCEQ RFP Els Project (Summer 2021)
2026 Fleet and Pre-2012 Controls without Growth	2011 (Base Year)	2026 Fleet and Pre-2012 Controls	TCEQ VOSD Els Project (Fall 2021)
2026 Fleet and Pre-2012 Controls with Growth	2026 (Attainment Year)	2026 Fleet and Pre-2012 Controls	TCEQ VOSD Els Project
2026 Control Strategy	2026 (Attainment Year)	2026 Control Strategy	TCEQ RFP Els Project

¹ Pre-2012 controls rates are for the evaluation year fleet (2026) but exclude control measures put into effect after the 2011 base year (e.g., no implementation of the Tier 3 standards which started in 2017).

² The TCEQ's Reasonable Further Progress (RFP) Els (June 2021) and pre-2012 controls VMT offset demonstration (VOSD) Els (October 2021) for DFW and HGB nonattainment area counties were developed by NCTCOG and TTI, respectively.

Separation of cold soak emissions is a complex problem due to a MOVES model output limitation when using the model in "county scale", as is required for developing emission estimates for SIPs. MOVES county scale off-network emission results are needed at the operating mode level to enable separation of cold soak operating mode emissions for the VMT offset demonstrations, but this feature is not available. MOVES county scale internally calculates and aggregates the operating mode emissions results for output by the MOVES emissions process categories.

NCTCOG and TTI produced the on-road mobile source Els listed in Table 1 using the required MOVES "county scale" resulting in output by emissions process. The MOVES on-road evaporative emissions processes are:

- fuel permeation,
- fuel tank vapor venting, and
- fuel leaks.

Each of these evaporative processes is composed of the three operating modes:

- cold soaking (unrelated to VMT or trips),
- hot soaking (related to VMT or trips), and
- operating or running (related to VMT or trips).

Consequently, the challenging work documented within this report was performed to calculate and separate the cold soak VOC emissions component from the off-network process-level emission results of the existing MOVES DFW and HGB on-road mobile source Els. In addition to the writing of this report, the overall project consisted of two

main tasks: 1) methodology research and testing, and 2) method application and emissions estimation.

In the first phase, three general methods were conceptualized, designed, and tested. Although the initial goal for each method was to isolate cold soak emissions for all three off-network evaporative processes, due to complexities of the MOVES vapor venting emissions algorithms and limitations of MOVES advanced features output, and under resource constraints, it was feasible only to estimate and separate the cold soak permeation and liquid leak emissions using MOVES.

The selected method involved the calculation and application of cold soak operating mode emissions fractions of total VOC emissions by emission process types. The operating mode emission fractions for each process were developed as a combination of emission rate ratios and activity ratios for each operating mode. Data needed for calculating the operating mode activity ratios was acquired by running MOVES with "advanced features" and "evaporative operating mode distribution generator" selected, using inputs from the DFW and HGB RFP EI analyses. The operating mode emission rate ratios were calculated using MOVES algorithms and values from EPA's MOVES evaporative emissions technical report (since MOVES advanced features output did not provide the needed emission rates)⁴.

The modified goal was therefore to split two of the three off-network evaporative process (fuel permeation and fuel leaks) emissions totals into operating mode components. This thereby enabled exclusion of the cold soak emissions portion from the process totals. Thus, the updated EIs from this analysis include total on-road mobile source VOC emissions, except for permeation and liquid leak VOC evaporative emissions estimated to have occurred during vehicle cold soaks. The regional VOC EI results excluding cold soak permeation and liquid leak VOC emissions, as prepared for the HGB and DFW VMT offset demonstrations are summarized in Table 2 and Table 3. The general formula applied to produce these desired results is:

$$VOC_{New} = VOC_{Old} - VOC_{Cold\ Soak,Per} - VOC_{Cold\ Soak,Leak} \quad (1)$$

Where:

VOC_{New} = VOC EI results excluding cold soak permeation and liquid leak VOC emissions.

VOC_{Old} = VOC EI results in original, standard EIs.

$VOC_{Cold\ Soak,Per}$ = cold soak permeation VOC emissions.

⁴ *Evaporative Emissions from Onroad Vehicles in MOVES3* (EPA, November 2020).

$VOC_{\text{Cold Soak,Leak}}$ = cold soak liquid leak VOC emissions.

To produce the results presented in Table 2 and Table 3, the standard (tab-delimited), county level summaries of the four TDM link-based EIs for each area (76 county-level EIs) were post-processed, splitting the off-network evaporative permeation and liquid leak process emissions into cold soak, running, and hot soak components. From these post-processed county files, the VOC emissions were extracted, excluding the off-network permeation and off-network liquid leak cold soak VOC emissions, and summarized by county and at the area level.

The post-processing was coded in the Python programming language. All of the files pertinent to the analysis were provided to TCEQ, to included spreadsheets of the extracted, post-processed VOC summaries by county and area. An electronic data submittal description is provided in Appendix A.

Table 2. Updated HGB Eight-County Area Summer Weekday On-Road Mobile Source Emissions Inventories for the VMT Offset Demonstration (tons/day).

RFP 2011 Base Year –2011 VMT and emissions controls

Year	VMT	VOC Total (<i>before removing cold soak permeation and liquid leaks VOC</i>)	Cold Soak Permeation VOC	Cold Soak Fuel Leaks VOC	VOC Total (<i>after removing cold soak permeation and liquid leaks VOC</i>)
2011	145,516,066	84.12	12.26	3.02	68.84

VMT Offset Scenario A – 2026 with no VMT growth from 2011 and no new Post-2011 control measures

Year	VMT	VOC Total (<i>before removing cold soak permeation and liquid leaks VOC</i>)	Cold Soak Permeation VOC	Cold Soak Fuel Leaks VOC	VOC Total (<i>after removing cold soak permeation and liquid leaks VOC</i>)
2026	145,516,066	28.80	4.28	3.05	21.48

VMT Offset Scenario B –2026 with VMT growth from 2011 and no new Post-2011 control measures

Year	VMT	VOC Total (<i>before removing cold soak permeation and liquid leaks VOC</i>)	Cold Soak Permeation VOC	Cold Soak Fuel Leaks VOC	VOC Total (<i>after removing cold soak permeation and liquid leaks VOC</i>)
2026	208,706,310	39.77	6.26	4.42	29.09

RFP 2026 Control Strategy –2026 VMT and emissions controls

Year	VMT	VOC Total (<i>before removing cold soak permeation and liquid leaks VOC</i>)	Cold Soak Permeation VOC	Cold Soak Fuel Leaks VOC	VOC Total (<i>after removing cold soak permeation and liquid leaks VOC</i>)
2026	208,706,310	28.98	3.89	4.26	20.83

Table 3. Updated DFW 10-County Area Summer Weekday On-Road Mobile Source Emissions Inventories for the VMT Offset Demonstration (tons/day).

RFP 2011 Base Year –2011 VMT and emissions controls

Year	VMT	VOC Total (<i>before removing cold soak permeation and liquid leaks VOC</i>)	Cold Soak Permeation VOC	Cold Soak Fuel Leaks VOC	VOC Total (<i>after removing cold soak permeation and liquid leaks VOC</i>)
2011	186,852,708	106.98	17.81	3.83	85.34

VMT Offset Scenario A – 2026 with no VMT growth from 2011 and no new Post-2011 control measures

Year	VMT	VOC Total (<i>before removing cold soak permeation and liquid leaks VOC</i>)	Cold Soak Permeation VOC	Cold Soak Fuel Leaks VOC	VOC Total (<i>after removing cold soak permeation and liquid leaks VOC</i>)
2026	186,852,708	36.09	5.93	3.80	26.36

VMT Offset Scenario B –2026 with VMT growth from 2011 and no new Post-2011 control measures

Year	VMT	VOC Total (<i>before removing cold soak permeation and liquid leaks VOC</i>)	Cold Soak Permeation VOC	Cold Soak Fuel Leaks VOC	VOC Total (<i>after removing cold soak permeation and liquid leaks VOC</i>)
2026	246,707,882	47.74	7.83	5.02	34.88

RFP 2026 Control Strategy –2026 VMT and emissions controls

Year	VMT	VOC Total (<i>before removing cold soak permeation and liquid leaks VOC</i>)	Cold Soak Permeation VOC	Cold Soak Fuel Leaks VOC	VOC Total (<i>after removing cold soak permeation and liquid leaks VOC</i>)
2026	246,707,882	35.61	5.01	4.85	25.74

1.0 INTRODUCTION

The Texas Commission on Environmental Quality (TCEQ) works with local planning districts, the Texas Department of Transportation (TxDOT), and the Texas A&M Transportation Institute (TTI) to provide on-road mobile source emissions inventories of air pollutants. The TxDOT typically funds transportation conformity determinations required under the 40 Code of Federal Regulations Part 93. The TCEQ funds mobile source emissions inventory work in support of Federal Clean Air Act (FCAA) requirements, such as supporting the attainment of the National Ambient Air Quality Standard (NAAQS) and the study and control of hazardous air pollutants, including those from motor vehicles and/or motor vehicle fuels, as mandated under the FCAA sections 202 and 211.

To come into alignment with the 9th Circuit Court of Appeals decision in *Association of Irrigated Residents v. EPA* (632 F.3d 584), the U.S. Environmental Protection Agency (EPA) published a guidance document, EPA-420-B-12-053, in August 2012. This document gives an example of how States can demonstrate the FCAA-required vehicle miles traveled (VMT) offset demonstration by preparing and analyzing four different emissions inventories (EIs). To summarize the process, a fully controlled attainment year EI must be less than that of an artificial inventory, wherein the artificial inventory would:

“Assume that no new transportation control strategies or transportation control measures (TCMs) beyond those already credited were added or implemented after the base year and would also assume that there was no growth in VMT between the base year and attainment year.” (EPA-420-B-12-053).

While reviewing other states' state implementation plan (SIP) submittals, a California VMT offset demonstration was identified that used a slightly modified approach. This alternate approach removed diurnal evaporative (or cold soak) emissions that are unrelated to VMT from both the fully controlled and artificial attainment year inventories. The EPA proposed approval of California's SIP submittal containing the VMT offset demonstration for the San Diego ozone nonattainment area on April 8, 2021.

This modified approach is not directly available for use in Texas, as the California Air Research Board relies upon the use of an on-road vehicle emissions model (EMFAC) only approved for use by California. The EPA's latest version of the Motor Vehicle Emissions Simulator (MOVES) model, MOVES3 (in county scale mode, required for SIP on-road EI development) aggregates VMT and non-VMT dependent operating modes into process-level rates. This results in aggregate emission rates for some processes making it difficult to separately quantify the portions of emissions related to and un-related to VMT.

TCEQ will need to perform VMT offset demonstration analyses for the DFW and HGB SIP revision to show whether there are emissions that must be offset.⁵ Four existing EIs as described in Table 1 are required for the VMT offset demonstrations.⁶ These existing EIs, however, reflect total on-road mobile source emissions, which include the diurnal or “cold soak” operating mode evaporative emissions that are unrelated to VMT and trips. Evaporative emissions during vehicle cold soaks result from diurnal temperature effects on fuel systems of non-operating, cooled down vehicles (i.e., cold soaking vehicles), not from vehicles during travel (running or operating) or hot vehicles at trip ends (hot soaking). Cold soak emissions therefore can be excluded from the VMT offset demonstration EIs.⁷

Separation of cold soak emissions is a complex problem due to a MOVES model output limitation modeling in “county scale”, as is required for developing emission estimates for SIPs. MOVES county scale off-network emission results are needed at the operating mode level to enable separation of cold soaks for the VMT offset demonstrations. MOVES county scale, however, lacks an operating mode output option. MOVES internally aggregates operating mode results into emissions process categories output by the model.

NCTCOG and TTI produced the on-road mobile source EIs listed in Table 1 using the required “county scale” MOVES option resulting in MOVES output by emissions process. Table 4 and Table 5 summarize the emission results of the existing MOVES DFW and HGB on-road mobile EIs listed in Table 1. The MOVES on-road evaporative emissions processes are:

- fuel permeation,

⁵ The VMT offset demonstration (VOSD) is to show that, from the base year to the attainment year, projected growth in VMT will not hinder the nonattainment area’s progress toward attainment of the EPA’s 2008 eight-hour ozone standard. The EPA’s VOSD guidance is available at this link:

[EPA VMToffset guide](#)

⁶ TTI and the North Central Texas Council of Governments (NCTCOG) employed standard TDM link-based EI methods to develop the four MOVES county scale EIs. The EI development reports are: *Houston-Galveston-Brazoria (HGB) 2008-Eight-Hour Ozone Reasonable Further Progress (RFP) On-Road Mobile Emissions Inventories* (TTI, June 2021); *Houston-Galveston-Brazoria (HGB) On-Road Mobile Vehicle Miles Traveled (VMT) Offset Emissions Inventories* (TTI, October 2021); *Dallas-Fort Worth Motor Vehicle Emissions Simulator 3 (MOVES3)-Based Reasonable Further Progress On-Road Emissions Inventories and Control Strategies Reductions for Analysis Years 2011, 2017, 2018, 2020, 2023, 2026, and 2027* (NCTCOG, August 2021); *Dallas-Fort Worth (DFW) On-Road Mobile Vehicle Miles Traveled (VMT) Offset Emissions Inventories* (NCTCOG, October 2021).

⁷ Limiting VOSD analyses to emissions only related to VMT or vehicle trips by excluding cold soak evaporative emissions is used by California as detailed in the report at this link: [CARB report](#)

- fuel tank vapor venting, and
- fuel leaks.

Each of these evaporative processes are composed of the three operating modes:

- cold soaking (unrelated to VMT or trips),
- hot soaking (related to VMT or trips),
- operating or running (related to VMT or trips).

Consequently, the challenging work documented within this report was performed to calculate and separate the cold soak VOC emissions component from the off-network process-level emission results of the existing MOVES DFW and HGB on-road mobile source Els. In addition to the writing of this report, the project consisted of two main tasks: 1) methodology research and testing, and 2) method application and emissions estimation.

Table 4. Existing HGB Eight-County Area Summer Weekday On-Road Mobile Source Emissions Inventories for the VMT Offset Demonstration (tons/day).

RFP 2011 Base Year –2011 VMT and emissions controls

Year	VMT	VOC Total (before removing cold soak permeation and liquid leaks VOC)
2011	145,516,066	84.12

VMT Offset Scenario A – 2026 with no VMT growth from 2011 and no new Post-2011 control measures

Year	VMT	VOC Total (before removing cold soak permeation and liquid leaks VOC)
2026	145,516,066	28.80

VMT Offset Scenario B –2026 with VMT growth from 2011 and no new Post-2011 control measures

Year	VMT	VOC Total (before removing cold soak permeation and liquid leaks VOC)
2026	208,706,310	39.77

RFP 2026 Control Strategy –2026 VMT and emissions controls

Year	VMT	VOC Total (before removing cold soak permeation and liquid leaks VOC)
2026	208,706,310	28.98

Table 5. Existing DFW 10-County Area Summer Weekday On-Road Mobile Source Emissions Inventories for the VMT Offset Demonstration (tons/day).

RFP 2011 Base Year –2011 VMT and emissions controls

Year	VMT	VOC Total <i>(before removing cold soak permeation and liquid leaks VOC)</i>
2011	186,852,708	106.98

VMT Offset Scenario A – 2026 with no VMT growth from 2011 and no new Post-2011 control measures

Year	VMT	VOC Total <i>(before removing cold soak permeation and liquid leaks VOC)</i>
2026	186,852,708	36.09

VMT Offset Scenario B –2026 with VMT growth from 2011 and no new Post-2011 control measures

Year	VMT	VOC Total <i>(before removing cold soak permeation and liquid leaks VOC)</i>
2026	246,707,882	47.74

RFP 2026 Control Strategy –2026 VMT and emissions controls

Year	VMT	VOC Total <i>(before removing cold soak permeation and liquid leaks VOC)</i>
2026	246,707,882	35.61

1.1 OBJECTIVE

The purpose of this document is to describe the work performed by TTI to develop and apply a method to on-road mobile source EIs to separate emissions into the sub-process operating modes using the EPA Motor Vehicle Emissions Simulator (MOVES) model. This enabled TTI to isolate and quantify EI components dependent on different emission rate and activity input parameters. These isolated EI components are needed by TCEQ to help support the Dallas Fort-Worth (DFW) and Houston-Galveston-Brazoria (HGB) state implementation plan (SIP) revision for the 2008 eight-hour ozone National Ambient Air Quality Standard (NAAQS).

In addition to calculating EIs, this project involves the development of electronic deliverables that were post-processed from the existing EI results into formats suitable for reporting and air quality planning. These outputs include:

- Emissions inventory data files:
 - EI summaries (spreadsheet file).
 - EI utility standard output files – standard tab-delimited, hourly and 24-hour EI summaries by county, MOVES source use type (SUT) and fuel type (FT) combination (or vehicle type), and TDM roadway class.
- Emissions factor data files:
 - MOVES model input data, build and run files, as well as post-processing adjustment factors and code script files.

1.2 SUMMARY OF MODELING METHODOLOGY

Each updated EI was calculated using the emission results from the existing EI, which applied a detailed MOVES rates-per-activity method based on the regional TDM. This approach calculates on-network emissions at the scale of each link defined by the regional TDM outputs, and off-network emissions at the county level.

The TTI operating mode based evaporative emission estimation methods were performed in three steps, simplified below and described in more detail in later sections:

1. **Calculate Operating Mode Based Emission Rates Ratios:** The operating mode based rates ratios relevant to evaporative emissions in the analysis area and the VMT offset scenarios were calculated based on outputs from MOVES3 runs with

local inputs such as temperature and humidity, fuel formulations, etc, and evaporative emission rates algorithms in MOVES3 technical documents.

2. **Calculate Operating Mode Based Vehicle Activity Ratios:** The operating mode based vehicle activity ratios relevant to evaporative emissions in the analysis area and the VMT offset scenarios were calculated based on the operating mode distribution outputs from MOVES runs with local inputs such as temperature and humidity, fuel formulations, etc.
3. **Calculate Operating Mode Based Evaporative Emissions Ratios:** The operating mode based emissions ratios were calculated based on the emission rates ratios calculated in step 1 and activity ratios calculated in step 2.
4. **Calculate Operating Mode Based Evaporative Emissions:** The operating mode based evaporative emissions ratios calculated in step 3 were applied to existing EI outputs to separate evaporative emissions into the sub-process operating modes.

Postprocess EI Outputs: Outputs (for each pollutant) were post-processed into the same formats as the original, existing EI summaries with VOC sub-process operating mode components included, and electronic deliverables were provided for reporting purposes and air quality planning.

Subsequent sections of this report describe these simplified steps in more detail.

1.3 EMISSIONS INVENTORIES SCOPE

The scope of the original EIs is detailed in the referenced TTI and NCTCOG HGB and DFW RFP and VMT offset EI reports.

The following is a brief summary of the scope (entities modeled and data inputs).

Geography, Time Period, and Day Type:

- Houston – Brazoria - Galveston (HGB)
 - Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller counties.
- Dallas - Fort Worth (DFW)
 - Collin, Dallas, Denton, Ellis, Johnson, Kaufman, Parker, Rockwall, Tarrant, Wise counties.
- Analysis year VMT offset EI scenarios (the four as described in Table 1).
- Summer season of June through August.
- Weekday activity (average Monday through Friday).

Source Use Types, Activity Types, Emissions Processes, and Operating Modes:

- *Source use and fuel types (the various combinations of these are referred to as vehicle types) modeled:* See .
- *Traffic activity modeled:* VMT, vehicle starts, hotelling hours (classified by auxiliary power unit [APU], engine on, engine off), source hours parked, off-network idling.
- *Vehicle-based emissions processes modeled:* running exhaust; crankcase running exhaust; start exhaust; crankcase start exhaust; extended idle exhaust; crankcase extended idle exhaust; auxiliary power exhaust; evaporative permeation; evaporative fuel vapor venting; evaporative liquid leaks; brakewear; tirewear.
- *Vehicle-based emissions operating modes separately modeled:* off-network cold soak, running, and hot soak for evaporative liquid leaks and permeation processes.
- *Refueling emissions processes modeled:* not applicable.

Table 6. MOVES SUT/Fuel Types (Vehicle Types).

SUT ID	SUT Description	SUT Abbreviation ¹	Fuel Types
11	Motorcycle	MC	Gasoline
21	Passenger Car	PC	Gasoline, Diesel
31	Passenger Truck	PT	Gasoline, Diesel
32	Light Commercial Truck	LCT	Gasoline, Diesel
41	Other Buses	OBus	Gasoline, Diesel
42	Transit Bus	TBus	Gasoline, Diesel
43	School Bus	SBus	Gasoline, Diesel
51	Refuse Truck	RT	Gasoline, Diesel
52	Single Unit Short-Haul Truck	SUSHT	Gasoline, Diesel
53	Single Unit Long-Haul Truck	SULHT	Gasoline, Diesel
54	Motor Home	MH	Gasoline, Diesel
61	Combination Short-Haul Truck	CSHT	Gasoline, Diesel
62	Combination Long-Haul Truck	CLHT	Diesel

¹ The SUT/fuel type, or vehicle type, labels are the combined SUT abbreviation and fuel type names separated by an underscore (e.g., MC_Gas, RT_Diesel, and SBus_Gas are gasoline-powered motorcycles, diesel-powered refuse trucks, and gasoline-powered school buses, respectively).

Pollutants:

- VOC; CO; NO_x; NH₃; SO₂; atmospheric CO₂; primary PM₁₀ - exhaust, brakewear, and tirewear; and primary PM_{2.5} - exhaust, brakewear, and tirewear
 - VOC evaporative emissions with sub-process operating modes were updated.

- Other pollutants including CO; NO_x; NH₃; SO₂; atmospheric CO₂; primary PM₁₀ - exhaust, brakewear, and tirewear; and primary PM_{2.5} - exhaust, brakewear, and tirewear remain the same as existing EIs.

Emission Rate (MOVES) Input Data and Adjustments and Traffic Activity Input Data:

- As detailed in the referenced NCTCOG and TTI RFP and VMT offset EI reports.

Emissions inventory Outputs:

The following output files were updated by county in formats required by TCEQ.

- Emissions inventory data files:
 - EI summaries (spreadsheet file).
 - EI utility standard output files – standard tab-delimited, hourly and 24-hour EI summaries by county, MOVES SUT and fuel type combination (or vehicle type), and TDM roadway class.
- Emissions factor data files:
 - MOVES model input files, as well as post-processing adjustment factors (i.e., MOVES county input databases [CDBs], CDBs, MOVES run specification [MRS] files), and
 - Calculation code script files.

1.4 REPORT STRUCTURE

This report is further divided into the following sections.

- Section 2 details the research performed to develop three methods of which one was proposed, along with a pre-analysis plan, for post-processing existing EI files by separating the off-network evaporative emissions into operating mode components.
- Section 3 details the application of the selected method to post-process the HGB and DFW EIs to enable the removal of the off-network cold soak permeation and fuel leak evaporative emissions.
- Section 4 and Section 5 complete the narrative by summarizing conclusions, suggesting continuing research, and a discussion of quality assurance and quality control.
- The list of references is followed by the set of appendices to complete the report.

2.0 METHODOLOGY RESEARCH AND TESTING

In this initial phase of the project, the TTI project team conducted the literature review for developing potential methods that can be used to isolate and quantify operating-mode level off-network evaporative emissions. The proposed methods were developed, vetted, and tested by the TTI team on the HGB EIs to help identify the level of confidence and accuracy associated with each method. TTI proposed a selected method along with a plan for application, which TCEQ subsequently approved for use.

2.1 LITERATURE REVIEWS

The TTI team first conducted literature reviews of particular EPA MOVES model technical reports (on model overview and evaporative emissions) and of a report on a study about delineating evaporative process emissions by operating mode. These reviews provided information useful in laying out the initial methods for extracting evaporative emissions by mode. This section briefly summarizes pertinent information from the literature reviews.

2.1.1 Overview of EPA's Latest Available MOVES Model – MOVES3

EPA's MOVES model is an emissions modeling system using a bottom-up disaggregated algorithm to estimate emissions generated from on-road mobile sources such as passenger cars, heavy-duty trucks, buses, and non-road equipment such as portable generators and construction equipment.

The EPA released the latest version of the MOVES modeling system (MOVES3) in November 2020 (followed by several version updates) along with technical guidance on using the model for SIP emissions inventories. The MOVES3 model estimates emissions from 1990 and 1999 through 2060, from on-road and non-road sources at the national level, county level, and project level. Operating mode based emission rates are consistent across three levels for the on-road module, except that evaporative emission rates are not available from MOVES project scale analyses.

MOVES3 incorporates the following new regulations and new features beyond those inherited from previous generations of MOVES⁸:

- New Regulations

⁸ EPA. 2021. Overview of EPA's Motor Vehicle Emission Simulator (MOVES3), EPA-420-R-21-004, Office of Transportation and Air Quality. March 2021.

- Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2 Rule published in 2016, and
- Safer Affordable Fuel Efficient (SAFE) Vehicles Rule.
- New Features
 - Off-network Idle (ONI) activity,
 - Glider trucks,
 - Increased detail for heavy-duty vehicles,
 - Updated emission rates, and
 - Updated fuel characteristics, vehicle populations, and activity.

The MOVES model estimates emissions of multiple pollutants, multiple processes, and multiple vehicle types or equipment types. In the MOVES model, the following on-road processes are included⁸:

- Running exhaust,
- Start exhaust,
- Hotelling Emissions (Extended Idle Exhaust and Auxillary Power Exhaust),
- Crankcase,
- Brakewear,
- Tirewear,
- Evaporative Permeation,
- Evaporative Fuel Vapor Venting,
- Evaporative Fuel Leaks, and
- Refueling Displacement Vapor and Spillage Loss.

Among all the on-road emissions processes, permeation, fuel vapor venting, fuel leaks, and refueling displacement vapor and spillage loss emissions are the evaporative emissions processes estimated in the MOVES model. The following section gives the details of these evaporative emissions modules in the current MOVES3 model, excluding the refueling processes, as refueling-related emissions are a component of the TCEQ's area source EI, separate from the on-road mobile source EI.

2.1.2 Evaporative Emissions in the MOVES Model

The MOVES model classifies evaporative emissions based on different types of evaporative activity, with the following processes⁹:

- Evaporative permeation – The permeation of hydrocarbons through materials in the fuel system.
- Evaporative tank vapor venting – Vapor lost by fuel system into the atmosphere.
- Evaporative liquid leaks – Fuel leaking and then evaporating.
- Refueling Emissions – Spillage and vapor lost as a result of refueling activity.

In MOVES, “operating mode” is the concept to describe the vehicle activity status for different emission processes. Each of the non-refueling-related evaporative emission processes listed in Table 8 can be modeled by a mix of the evaporative emission-related operating modes listed in Table 7 and model year groups listed in Table 9. However, the MOVES model’s resulting evaporative emission rates or emissions output are aggregations by process (i.e., permeation, vapor venting, and liquid leaks) and are not available by operating mode. (Note that although refueling emissions processes are not applicable, as refueling is designated as an area source category, they are listed for information completeness.)

Table 7. MOVES Evaporative Process Operating Modes⁹.

Operating Mode ID	Operating Mode Description
150	Hot Soaking
151	Cold Soaking
300	Engine Operating (All running)

Table 8. MOVES Evaporative Processes⁹.

Process ID	Emission Process Description
11	Evap permeation
12	Evap vapor venting losses
13	Evap liquid leaks
18	Refueling displacement vapor losses
19	Refueling fuel spillage

⁹ EPA. 2020. Evaporative Emissions from Onroad Vehicles in MOVES3, EPA-420-R-20-012, Office of Transportation and Air Quality. November 2020.

Table 9. Model Year Groups for Evaporative Emissions in MOVES⁹.

Model Year Group	Evaporative Emissions Standard or Technology Level
1971-1977	Pre-control
1978-1995	Early control
1996	80 percent early control, 20 percent enhanced evap
1997	60 percent early control, 40 percent enhanced evap
1998	10 percent early control, 90 percent enhanced evap
1999-2003	100 percent Enhanced evap
2004-2015	Tier 2, LEV II
2016-2017	40 percent Tier 3
2018-2019	60 percent Tier 3
2020-2021	80 percent Tier 3
2022+	100 percent Tier 3

The MOVES model literature summarized over a decade of research outcomes used to help modernize the evaporative on-road mobile emissions modeling module. Many variables are considered and applied in calculating the operating mode based processes of evaporative emissions in MOVES⁹:

- Temperatures:
 - Ambient temperature,
 - Fuel tank temperature,
- Model year group (surrogate for technology and standard),
- Vehicle age,
- Vehicle class¹⁰:
 - Passenger vehicle,
 - Motorcycle,
 - Short/Long-haul trucks,
- Fuel properties
 - Ethanol content,
 - Reid vapor pressure (RVP),
- Failure modes, and
- Presence of inspection and maintenance (I/M) programs.

¹⁰ The data used for the MOVES evaporative emissions analysis was collected on light-duty gasoline vehicles but was also applied to heavy-duty gasoline vehicles since heavy-duty gasoline data was not available at the time of EPA's analysis.

In MOVES3, the advanced features tab of the graphical user interface allows users to generate default/calculated tables not available in the standard output (listed in a later section) from the following evaporative emissions related MOVES generator components involving the variables listed above:

- Evaporative Operating Mode Distribution Generator,
- Tank Temperature Generator,
- Tank Fuel Generator, and
- Fuel Effects Generator.

The following sections summarize the work from MOVES technical documents on how evaporative emissions in MOVES are calculated in each of the evaporative processes (excluding refueling), with an emphasis on the different evaporative operating modes.

2.1.2.1 Evaporative Permeation

Evaporative permeation emissions are hydrocarbons from the fuel system permeating through the surrounding vehicle materials, such as pipelines, fuel tanks, and other plastic or rubber vehicle components. In MOVES, the base permeation emission rates are estimated by different tests, and then adjustment equations and ratios have been applied to the base rates to model the impact of tank temperatures and fuel properties. Table 10 lists the permeation base rates in the MOVES model. Equation 2 (derived from the E-65 permeation study) is applied in the MOVES model to calculate the adjustment for the tank temperatures to the base permeation rate. MOVES estimated the ethanol effect on evaporative emissions with a mixed model; Table 11 lists the fuel adjustments on evaporative permeation emissions used for E5 through E85 ethanol/gasoline blends for the model year groupings used in MOVES.

$$P_{adj} = P_{base} e^{0.0385(T_{Tank} - T_{base})} \quad (2)$$

Where:

P_{base} = Base Permeation Rate (See Table 4).

T_{tank} = Tank Temperature (different for different operating modes).

T_{base} = Base Temperature for a given cycle (72F in test data applied by MOVES).

Table 10. MOVES Base Permeation Rates at Base Temperature (72F)⁹.

First Model Year	Last Model Year	Age Group	Base Rate
1960	1970	20+	0.311
1971	1977	10-14	0.192
		15-19	0.229
		20+	0.311
1978	1995	0-5	0.0554
		6-9	0.0913
		10-14	0.124
		15-19	0.148
		20+	0.201
1996	1996	0-5	0.0464
		6-9	0.0751
		10-14	0.0751
		15-19	0.12
		20+	0.163
1997	1997	0-5	0.0373
		6-9	0.0589
		10-14	0.0784
		15-19	0.0929
		20+	0.125
1998	1998	0-5	0.0147
		6-9	0.0183
		10-14	0.0216
		15-19	0.024
		20+	0.0293
1999	2015	All ages	0.0102
2016	2017	All ages	0.0072
2018	2019	All ages	0.0056
2020	2021	All ages	0.0041
2022	2060	All ages	0.0026

Table 11. Ethanol Effect for Permeation Emissions in MOVES⁹.

Model Years	Percent Increase due to ethanol (5-85%)
1995 and earlier	65.9
1996	75.5
1997-2000	107.3
2001 and later	113.8

2.1.2.2 Evaporative Tank Vapor Venting

In MOVES, evaporative vapor venting, or tank vapor venting (TVV) is the vapor generated by fuels in the tank and then escaped into the atmosphere. TVV is calculated based on Tank Vapor Generated (TVG) and adjusted by different fuel tank temperatures, ethanol content, RVP, and altitude. In MOVES, TVG is calculated as shown in Equation 3, with all the constants shown in Table 12.

$$TVG = Ae^{B \cdot RVP(e^{CT_x} - e^{CT_1})} \quad (3)$$

Where:

T₁ = Initial Temperature

T_x = Temperature at time x.

Table 12. TVG Constants for Equation 2⁹.

Constants	E0 Gasoline		E10 Gasoline	
	Sea Level	Denver Alt.	Sea Level	Denver Alt.
A	0.00817	0.00518	0.00875	0.00665
B	0.2357	0.2649	0.2056	0.2228
C	0.0409	0.0461	0.0430	0.0474

For cold soak TVV emissions, Diurnal Emissions Leaving To Atmosphere (DELTA) model was applied in MOVES to calculate TVV from TVG in the following modeling components:

- Calculate tank vapor generation (TVG) for various tank sizes, diurnal temperature changes, and fuel properties
- Predict tank vapor venting for arbitrary diurnal temperature and fuel property combinations for a single or fixed group of vehicles

- Integrate high evaporative leak rates and profiles into vapor venting predictions.

The following variables are used in the modeling approach, which are included in the MOVES default database in the "cumTvvCoeffs" table:

- Back Purge Factor,
- Average Canister Capacity,
- Tank Size,
- Tank Fill Fraction,
- Leak Fraction,
- Leak Fraction IM, and
- TVV Equation.

MOVES model considered the impact of off-cycle vehicle activity on cold soak evaporative permeation emission beyond same day until 5 days. In MOVES technical documents the following tables should provide the information on vehicle activities during the past 5 days:

- Samevehiclesoakingdaybasis,
- Samplevehicletrip,
- Samplevehicleday.

For hot soak TVV emissions, base rates represent emissions at sea level with RVP at 9.0 psi in MOVES, with an altitude adjustment and RVP adjustment similar to cold soak emission rates. Figure 1 shows the hot soak emission base rates in the MOVES model.

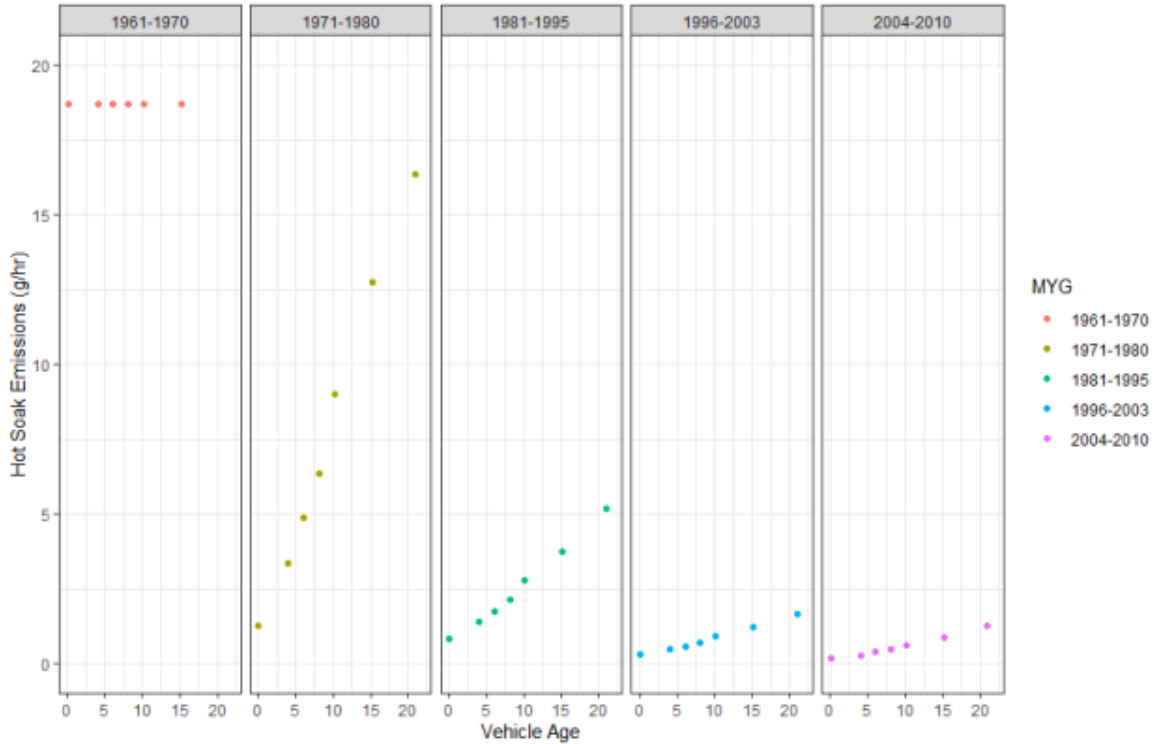


Figure 1. Hot Soak Emission Base Rates (9.0 RVP at Sea Level) in MOVES⁹.

Table 13 lists the pre-tier 2 running loss TVV emission rates in MOVES. Figure 2 shows the Tier 2 and later running loss TVV emission rates in MOVES. The running loss emission rates are adjusted by temperature and RVP coefficient in the evapRvpTemperatureAdjustment table in the default MOVES database.

Table 13. Pre-Tier 2 Running Loss TVV Emission Rates in MOVES (g/hour)⁹.

Model Year Group	TVV mean (g/hour)
Pre-1971	12.59
1971-1977	12.59
1978-1995	11.6
1996-2003	0.72

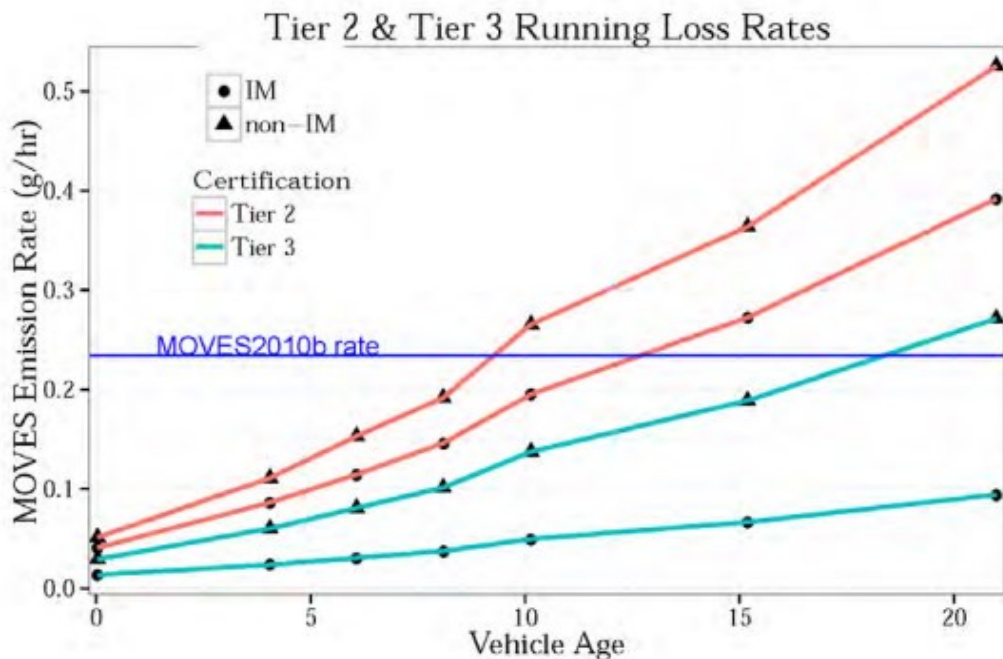


Figure 2. Tier 2 and Tier 3 Running Loss Emission Rates in MOVES⁹.

2.1.2.3 Evaporative Liquid Leaks

In MOVES, evaporative liquid leak emissions quantify any non-vapor fuel loss from the fuel system. Table 14 lists the fleet weighted liquid leak rate for different evaporative operating modes. Table 15 lists the same operating mode based weighted liquid leak rate for Tier 3 vehicles.

Table 14. Weighted Liquid Leak Emission Rates in MOVES (g/hour)⁹.

Age Group	Cold Soak	Hot Soak	Operating
0-9	0.009	0.017	0.158
10-14	0.025	0.048	0.450
15-19	0.075	0.145	1.360
20+	0.235	0.452	4.230

Table 15. Weighted Liquid Leak Emission Rates for Tier 3 Vehicles in MOVES (g/hour)⁹.

Age Group	Cold Soak	Hot Soak	Operating
0-9	0.007	0.013	0.123
10-14	0.019	0.037	0.342
15-19	0.058	0.113	1.054
20+	0.180	0.348	3.258

2.1.3 CARB Studies about Separating Evaporative Emissions

A California VMT offset demonstration used a slightly modified approach from prior VMT offset demonstration analyses. This alternate approach removed diurnal evaporative emissions (cold soak evaporative emissions) that are unrelated to VMT from both the fully controlled and artificial attainment year inventories. The EPA has proposed approval of California's SIP submittal containing the VMT offset demonstration for the San Diego ozone nonattainment area on April 8, 2021. In this study, the EMFAC model developed by California Air Resources Board (CARB) was applied.

The CARB released its latest available EMFAC model, EMFAC2021 on January 15, 2021. EMFAC2021 updated the evaporative emission module by using the same method as the MOVES3 model to estimate evaporative emissions with the California specific meteorological data, vehicle activity data, and fuel data.

The current evaporative emissions module follows the MOVES3 model to produce three evaporative emission processes, tank vapor venting, permeation, and liquid leak with three modes of activity: cold soak (diurnal), running, and hot soak modes. On the other hand, EMFAC2021 is implemented to model differently as compared to MOVES3¹¹ by using:

- Different vehicle classes,
- California specific meteorological data, vehicle activity, and fuel information,
- Tank temperature profiles preprocessed from MOVES, and
- Evaporative emissions outputs by all activity operating modes.

Based on the technical documentation, besides implementation to follow the MOVES3 evaporative emission processes, the EMFAC2021 evaporative emissions module has the

¹¹ CARB. 2021. EMFAC2021 Volume III Technical Document, Version 1.0.1, California Air Resource Board. April 2021.

same basic empirical estimation method which was started in EMFAC2000 for cold soak (diurnal), resting loss, hot soak, and running loss emissions¹²:

- Develop base emission rates as a function of ambient temperature and fuel Reid Vapor Pressure (RVP),
- Develop fuel and temperature correction factors,
- Develop multi-day correction factors,
- Develop evaporative emission regime growth rates, and
- Assess the impact of I/M and OBD II on hot soak emissions.

The consistency with the MOVES3 methodology and the level of detail of EMFAC2021 potentially make it a reliable source for providing the ratios of total emissions or emission rates among all activity operating modes, by running EMFAC2021 when using Texas-specific meteorological data, vehicle activity, and fuel information.

2.2 SUMMARY OF PROPOSED METHODOLOGIES

Based on the literature reviews on EPA'S MOVES3 and CARB's EMFAC2021, the following methodologies were proposed as candidates to help separate cold soak evaporative emissions that are unrelated to VMT from both the fully controlled and artificial attainment year inventories:

- Method 1 - Apply a direct aggregated emission ratio on total evaporative emissions to calculate cold soak emissions.
- Method 2 - Develop an aggregated ratio for operating mode based emission rates combined with the operating mode distribution from the MOVES model or other data sources to calculate the cold soak evaporative emissions.
- Method 3 - Conduct a disaggregated emission calculation, using disaggregated cold soak emission rates combined with the operating mode distribution from the MOVES model to calculate the cold soak emissions.

2.2.1 Method 1

Method 1 is a quick and direct method to separate the cold soak emissions from the total evaporative emissions by emissions processes. In each of the processes, an estimated ratio is provided to calculate the proportion of cold soak emissions. The

¹² California Air Resource Board (CARB), Chapter 5 of Technical Support Document for EMFAC2000, May 2000.

source of the ratio can be from previous studies. For example, Table 16 lists the comparison of statewide evaporative emissions among the operating modes in EMFAC2021. Assume in each of the evaporative processes, the ratio of cold soak emissions to the total emissions is the same as the ratio shown in Table 16. The cold soak emission estimations can be simplified as shown in Equation 4. The advantage of the method is the calculation is a straightforward application of a ratio to the emission quantities for each evaporative process. No additional details are required other than emission inventory results and this method provides a relatively conservative estimate of cold soak emissions. In contrast, the ratio estimated from a California study based on EMFAC2021 may be different than what MOVES may produce, which can be attributed to the different emission rates and the activity distribution used in MOVES.

$$E_{p,cold} = E_p \times \frac{E_{cold,CA}}{E_{cold,CA} + E_{hot,CA} + E_{run,CA}} \quad (4)$$

Where:

$E_{p,cold}$ = Cold soak evaporative emissions in process p.

E_p = Total evaporative emissions in process p.

$E_{cold,CA}$ = Statewide cold soak evaporative emissions in California in EMFAC2021 by analysis year

$E_{hot,CA}$ = Statewide hot soak evaporative emissions in California in EMFAC2021 by analysis year

$E_{run,CA}$ = Statewide running soak evaporative emissions in California in EMFAC2021 by analysis year

Table 16. Comparison of California Statewide Evaporative Emissions in EMFAC2021 among Operating Modes (tons/day)¹¹

Analysis Year	Cold Soak (Dirun)	Hot Soak	Run Loss
2010	~75	~35	~80
2020	~58	~21	~47
2030	~43	~25	~37
2040	~38	~10	~32
2050	~33	~8	~30

2.2.2 Method 2

As illustrated in Section 2.1.2, MOVES3 technical documents provided algorithms of evaporative emission rates and the MOVES3 advanced feature generator provided evaporative operating mode distribution tables. In each of the processes, the emissions are calculated as emission rates multiplied by the activity. The proportion of cold soak emissions can be estimated as a ratio of cold soak emission rates to total emission rates multiplied by the ratio of cold soak operating mode fractions to total operating mode fractions as Equation 5. The source for calculation of the ratio in emission rates and ratio in operating mode distribution is the MOVES3 model itself. These rates can be extracted from the MOVES outputs and technical documentation. The resolution of emissions and emission rates applied in this method is by the hour, which is consistent with the outputs in normal emission inventories. The complexity of calculations depends on the variation in emission rates by meteorological data, fleet composition and fuel property, and variations in operating mode by different locations and analysis years.

$$E_{p,cold} = \sum_h E_{p,h} \times \left(\frac{R_{er,cold,p,h} \times R_{opmode,cold,p,h}}{\sum_i R_{er,i,p,h} \times R_{opmode,i,p,h}} \right) \quad (5)$$

Where:

- $E_{p,cold}$ = Cold soak evaporative emissions in process p.
- $E_{p,h}$ = Total evaporative emission in process p, hour h.
- $R_{er,cold,p,h}$ = Ratio of cold soak evaporative emission rates to total evaporative emission rates in process p, hour h.
- $R_{opmode,cold,p,h}$ = Ratio of cold soak operating mode fractions to total operating mode fractions in process p, hour h.
- $R_{er,i,p,h}$ = Ratio of operating mode, i, evaporative emission rates to total evaporative emission rates in process p, hour h.
- $R_{opmode,i,p,h}$ = Ratio of operating mode fraction, i, to total operating mode fractions in process p, hour h.

2.2.3 Method 3

As shown in Section 2.1.2, the evaporative emission rates in the MOVES model are sensitive to vehicle ages and analysis years. It means for different vehicle ages in different analysis years, the operating mode based evaporative emission rates are different. Method 3 is built on this bottom-up disaggregated approach with model year and operating mode based evaporative emission rates calculated purely from the MOVES algorithm, combined with operating mode distributions and project area-specific analysis year and age distributions to calculate the cold soak evaporative emissions as shown in Equation 6. The method requires model year based emission rates as the starting point, which requires extra effort in MOVES model runs and is not the normal emission rates produced in the traditional SIP emission inventories process. In return, the method will show the most detailed characteristics of the MOVES modeling process of the evaporative emissions.

$$E_{p,cold} = \sum_{h,MY} (ER_{cold,p,h,MY} \times Opmode_{cold,p,h,MY}) \quad (6)$$

Where:

$E_{p,cold}$ = Cold soak evaporative emission in process p.

$ER_{cold,p,h,MY}$ = Emission rates of cold soak evaporative emission in process p, hour h, and model year MY.

$Opmode_{cold,p,h,MY}$ = Operating mode fraction of cold soak operating mode in process p, hour h, and model year MY.

2.2.4 Methods Analyses, Validations, and Recommendations

Table 17 lists the characteristics of three proposed methods for calculating cold soak emissions. Method 1 is a less onerous method with relatively lower accuracy. It fits the requirement when results are only needed to give the order of magnitude. Method 2 and method 3 are more laborious methods, with higher accuracies. The preparation time for method 3 is higher than method 2, due to the requirement of the model year based MOVES emission rates run. In addition, method 3 also provides the results in the most detailed way. The complexity of method 2 and method 3 is about the same, i.e., operating mode distributions and the emission rates vary over the analysis year, location, and model year. However, if either distribution is constant or has less variation, method 2 has the advantage of conducting fewer calculations while not losing the accuracy in estimating cold soak evaporative emissions. The TTI research team

conducted a series of test runs to see how operating mode distributions change in different scenarios.

Table 17. Characteristics of Proposed Methods.

Method ID	Aggregation Level	Difficulty	Accuracy	Level of Detail
Method 1	Aggregated ratio on analysis year emissions	Easy	Low	Analysis year based
Method 2	Aggregated ratio on analysis year emission rates	Normal	Medium/High	Analysis year based
Method 3	All disaggregated model year based emission calculation	Hard	High	Model year based

For test runs, the TTI research team selected the following 7 CDBs from the previous HGB 2008 Ozone Standard RFP project with different analysis years, different control strategies, and different counties to perform inventory mode runs with generator database output selected in MOVES3 advanced features:

- mvs31_rfp08stdh_2011cs2_48071_er_cdb_in
- mvs31_rfp08stdh_2017cs0_48039_er_cdb_in
- mvs31_rfp08stdh_2018cs1_48039_er_cdb_in
- mvs31_rfp08stdh_2020cs3_48039_er_cdb_in
- mvs31_rfp08stdh_2023cs0_48071_er_cdb_in
- mvs31_rfp08stdh_2026cs1_48039_er_cdb_in
- mvs31_rfp08stdh_2027cs2_48071_er_cdb_in

Table 18 lists the comparison notes from the test runs highlighting of the MOVES tables with no data differences. The tables highlighted mostly influence evaporative emissions. It indicates that evaporative emission related variables, like tank temperatures and soak activity distributions will not change in different scenarios in MOVES3.

Table 18. Comparison Notes of MOVES3 Test Runs for Seven HGB 2008 Ozone Standard RFP Scenarios*.

Generator Table Database Results (229 tables-- 18 tables with data and the rest empty)	
Tables with Data	Notes (no data differences for highlighted tables) *
averagetankgasoline	gasoline ETOH / RVP can vary by year and scenario (but not expected to vary by HGB county since all are in the same fuel region); data is the same for CS2 and CS3 for 2020 and later years; this most likely varies by fuel formulation
averagetanktemperature	No differences, except for countyID (note that one set of regional average temperatures were used in the RFP els analysis)
coldsoakinitialhourfraction	No differences, except for countyID
coldsoaktanktemperature	No differences, except for countyID (likely due to no variation in zonemonthhour input data)
criteriatio	These vary by model year, thus are different by analysis year, at least. (Another check would be to compare runs for the same year, but for different counties/scenarios, but need more runs to make these comparisons)
extendedidlehours	Different by scenarios, counties, years. (Data are by age)
generalfuelratio	By model year and age. Appears to vary only by fuel formulation
hotsoakeventbyhour	No differences
opmodedistribution	Differences, but differences look slight. (Exception is for motorcycles which appear to not vary between runs)
samplevehicletripbyhour	No differences
sho	Vary by year (i.e., runs 1 and 7) (expected to vary between counties and maybe scenarios, but can't tell from these runs)
soakactivityfraction	No differences
sourcebin	Vary by year (i.e., runs 1 and 7) (from these runs, can't tell between counties and scenarios)
sourcebindistribution	By model year data, different by year (can't tell between counties and scenarios from these runs)
sourcehours	Different by year (i.e., runs 1 and 7) (can't tell between counties and scenarios from these runs)
starts	Different by year (i.e., runs 1 and 7) (can't tell between counties and scenarios from these runs)
startspervehicle	No differences
zonemonthhour	No differences (except for zoneID)

*Notes on comparison of data in output tables between seven emission inventory mode runs using the following rate-per-activity mode CDBs:

With the test run information, TTI researchers performed a quick methods assessment using daily average emission ratios to assess the three proposed methods, by the following design:

- Method 1: Emission ratios estimated from Table 16.
- Method 2:
 - Option 1 (MOVES option), daily average emission ratios estimated from MOVES3 emission rates ratios and MOVES3 vehicle activity ratios.
 - Option 2 (Hybrid option), daily average emission ratios estimated from EMFAC2021 emission rates ratios and MOVES3 vehicle activity ratios.
 - EMFAC2021 emission rates runs were designed using daily average meteorology data as HGB area.
- Method 3: Emission ratios estimated from actual emission rates calculated from MOVES3 and MOVES3 vehicle activity ratios.

During the assessment, TTI researchers noticed that due to the complexity of the MOVES tank vapor venting emissions process algorithms and lack of usable information in the MOVES advanced features generator output, as well as time constraints, only permeation, and fuel leaks process emissions could be post-processed into operating mode components for Method 2 – option 1. Although Method 3 could produce more accurate rates information, the lack of the full set of information needed from MOVES rendered it not applicable for this analysis during the short time-frame available. Table 19 lists the quick assessment using daily fleet mix average emission ratios in the HGB test areas for Method 1, Method 2 – Option 1, and Method 2 – Option 2. The following conclusions are drawn from the methodology assessment.

- Method 1: this may not give benefits to this project since the EMFAC emission ratios are aggregated by all roadway types, source types, and all evaporative operating pollutant processes. For the same analysis year, the same emission ratios will be applied to the scenario which will only scale the existing deficit in total evaporative emissions.
- Method 2 – Hybrid Option: gives the overall benefits that we can get by excluding cold soak evaporative emissions from total evaporative emissions. It is a hybrid method using both MOVES3 and EMFAC2021. EMFAC2021 applied the same algorithm in the evaporative emissions calculations as MOVES3. However,

EMFAC2021 modeled emissions differently as compared to MOVES3 in the following categories:

- Different definitions of vehicle classes,
 - California specific meteorological data, vehicle activity, and fuel information,
 - Tank temperature profiles preprocessed from MOVES, and
 - Evaporative emissions outputs by all activity operating modes.
- Method 2 – MOVES Option: gives a conservative benefit estimate by excluding cold soak permeation and cold soak fuel leak emissions from total evaporative emissions. The comparison with Method 2 – Hybrid Option also validates the conservativeness of this method option. The option only uses the MOVES3 information from MOVES3 runs or MOVES3 technical documents, with local meteorological data, vehicle activity, and fuel information.

Table 19. HGB Eight-County Area Summer Weekday On-Road Mobile Source Emissions Inventories Quick Assessment for the VMT Offset Demonstration using Daily Average Emission Ratios (tons/day).

Scenarios	Before	Method 1	Method 2 – Option 1	Method 2 – Option 2
2011 base year	84.12	50.36	69.03	60.76
2026 pre-2012 wG	39.77	22.68	29.20	23.14
2026 pre – 2012 woG (ceiling)	28.80	16.42	21.56	17.38
2026 control strategy	28.98	16.52	20.78	16.48
2026 - ceiling	(-0.18)	(-0.10)	0.78	0.91

Considering the flexibility, complexity, and accuracy of the proposed methods, the TTI research team recommended method 2 - MOVES option for use in Task 4 to calculate and isolate cold soak evaporative emissions from the emission inventory results, which the TCEQ project manager supported.

2.3 PRE-ANALYSIS PLAN

This section provides the pre-analysis plan required under Task 3 of the PGA. As one component of the deliverables under Task 3, TTI developed a pre-analysis plan to outline the data sources, modeling, and post-processing to be performed when

applying the TTI recommended method to the specified EIs in Task 4. The following three subsections provide the pre-analysis plan.

2.3.1 Data Sources

The data needed for project implementation are in the categories needed for the development and the application of the methodology to estimate the appropriate emissions, rates, and other factors needed to separate out cold soak operating mode evaporative emissions from the evaporative process emissions totals. The county-level input CDBs and MRS, and the tab-delimited output files from these RFP emissions inventory projects are required. TTI will acquire the appropriate inputs and outputs of all scenarios from TCEQ on the following projects:

- 2008 Ozone Standard RFP HGB Emissions Inventories,¹³
- 2008 Ozone Standard VMT Offset HGB Emissions Inventories,
- 2008 Ozone Standard VMT Offset DFW Emissions Inventories, and
- 2008 Ozone Standard RFP DFW Emissions Inventories.

All data used as direct input or to produce inputs will be reviewed by TTI for suitability before use.

2.3.2 Estimating Cold Soak Evaporative Emissions

Based on recommended Method 2 – MOVES Option in the previous section, the TTI research team will conduct the following county-level analyses:

- Apply the input CDBs to the latest MOVES model to obtain the ratio of cold soak operating mode fractions to total evaporative operating mode fractions.
- Apply MOVES algorithms in evaporative emissions to calculate the ratio of cold soak evaporative emission rates to total evaporative emission rates in each evaporative process.
- Conduct post-processing work on the ratio of rates and ratio of operating mode fractions to calculate the ratio of cold soak emissions to total evaporative emissions in each evaporative process.

¹³ TTI has access to the HGB input and output files and will request the DFW inputs from TCEQ.

- Apply the post-processed ratio of cold-soak emission to the total evaporative emissions to tab-delimited output files to calculate and isolate cold soak evaporative emissions for both base scenarios and analysis year scenarios.
- Prepare the tab-delimited output files based on the analyses in the same format as emissions inventories output files.

After the final product is completed, all of the project data archives are compiled on a USB flash drive or an external drive for very large project data sets. A complete archive of the project data will be kept by TTI (emissions calculating scripts used in the process will be included). An electronic data submittal package will be produced along with a data description for delivery to TCEQ (on a USB flash or external hard drive, depending on needed storage space).

2.3.3 Quality Assurance

Basic criteria will be used to assure that the acceptable quality of the product is met – research staff will verify that the processes and products are as stated previously, including:

- a. Agreed methods, models, tools, and data are used;
- b. Input data preparation checks on fitting project purpose, completeness, and format;
- c. The required output data sets are produced in the appropriate formats;
- d. Identify and correct any deficiencies found during development and end-product quality checks (as discussed below); and
- e. Verify that aggregate emissions of evaporative operating modes are equal to the original total evaporative emissions from the HGB and DFW emissions inventories output tab files.

Where inconsistencies or deficiencies are found, the issue will be directly communicated to the responsible staff for correction (or the outside agency staff involved, if provided from outside of TTI, if needed). After a correction is made, the QA checks are performed again to ensure that the additional work resulted in the intended quality assured result, and the correction is noted in the QA record (the process is performed until the QA check is satisfied).

3.0 METHOD APPLICATION AND EMISSIONS ESTIMATION

This section describes TTI's application of the TCEQ-selected cold soak mode evaporative emissions estimation method to the DFW and HGB VMT offset EIs.

A brief overview is provided followed by details of the steps of the analysis for each of the evaporative processes. Data sources, assumptions, formulas, and tools used in the calculations are provided. This discussion is based on the HGB analysis. The DFW analysis was performed similarly with DFW area inputs.

As a part of this task, TTI submitted all the pertinent and applicable project data files (e.g., calculation and summary spreadsheets, and program code used in the application)¹⁴, as described in Appendix A, the electronic data submittal description.

3.1 OVERVIEW

Method 2 was selected for use. In summary, Method 2 produces a set of operating mode emissions ratios or fractions, for each specified process, which are multiplied by the emission process' total emissions to produce the operating mode emissions subtotals.¹⁵ The cold soak VOC emissions may then be removed from the standard EIs. However, due to the complexity of the MOVES tank vapor venting emissions process algorithms and lack of usable information in the MOVES advanced features generator output, as well as time constraints, only permeation, and fuel leaks process emissions were post-processed into operating mode components. It makes the overall methodology applied in this study more conservative in terms of the resulting estimated benefits as compared to the original design.

3.1.1 Key Formula

The operating mode emission ratio for a process is the product of the emission rate ratio for operating mode i and the activity ratio for a process p divided by the sum of this product of all three evaporative operating modes. In summary, the general formula for calculating cold soak emissions in Method 2 is shown as Equation 7:

¹⁴ MOVES county input databases and MOVES run specification files were from the prior RFP EI submittals.

¹⁵ During testing, two options were considered for Method 2 -Option 1 was selected, which uses only MOVES information (as opposed to the other option which incorporated some information from EMFAC).

$$Emission\ Ratio_{p,i} = \frac{Emission\ Rates\ Ratio_{p,i} \times Activity\ Ratio_{p,i}}{\sum_i Emission\ Rates\ Ratio_{p,i} \times Activity\ Ratio_{p,i}} \quad (7)$$

This general equation was used to calculate the off-network cold soak, running, and hot soak emissions ratios used for splitting permeation and liquid leak emissions into these three operating mode subcomponents. The operating mode distribution is hourly based on the MOVES model. The daily operating mode based cold soak emissions are calculated as the formula shown below as Equation 8:

$$\begin{aligned} E_{p,cold} &= \sum_h E_{p,h} \times R_{Emission,cold,p,h} \\ &= \sum_h E_{p,h} \times \left(\frac{R_{er,cold,p,h} \times R_{opmode,cold,p,h}}{\sum_i R_{er,i,p,h} \times R_{opmode,i,p,h}} \right) \end{aligned} \quad (8)$$

Where:

- $E_{p,cold}$ = Cold soak evaporative emissions in process p.
- $E_{p,h}$ = Total evaporative emission in process p, hour h.
- $R_{er,cold,p,h}$ = Ratio of cold soak evaporative emission rates to total evaporative emission rates in process p, hour h.
- $R_{opmode,cold,p,h}$ = Ratio of cold soak operating mode fractions to total operating mode fractions in process p, hour h.
- $R_{er,i,p,h}$ = Ratio of operating mode, i, evaporative emission rates to total evaporative emission rates in process p, hour h.
- $R_{opmode,i,p,h}$ = Ratio of operating mode fraction, i, to total operating mode fractions in process p, hour h.
- $R_{emission,cold,p,h}$ = Ratio of cold soak emission fractions to total emission fractions in process p, hour h.

3.1.2 Key Steps in the Process

Per the plan (Section 2.3.2), the TTI research team conducted the following county-level analyses in five main steps:

1. Applied the input CDBs to the latest MOVES model to *obtain the ratio of cold soak operating mode activity fractions* to total evaporative operating mode activity fractions.
2. Applied MOVES algorithms in evaporative emissions to *calculate the ratio of cold soak evaporative emission rates* to total evaporative emission rates in the permeation and liquid leak evaporative processes.

3. Conducted post-processing work on the ratio of rates and ratio of operating mode fractions to *calculate the ratio of cold soak emissions to total evaporative emissions* in the permeation and liquid leak evaporative processes.
4. Applied the post-processed ratio of cold-soak emission to the total evaporative emissions to tab-delimited output files to *calculate and isolate cold soak evaporative permeation and liquid leak emissions* for both base scenarios and analysis year scenarios.
5. **Prepared the tab-delimited output files** based on the analyses in the same format as emissions inventories output files.

Procedures of the steps in this process were performed in spreadsheets or coded in the Python programming language. The following sections provide details on key assumptions, input data sources, and outputs, if applicable (e.g., some intermediate results are internal data sets not output by the Python application), for each step of the process.

3.2 DEVELOPMENT OF OPERATING MODE ACTIVITY RATIOS

The first step in the process was to calculate the operating mode activity ratios using MOVES.

3.2.1 Inputs and Assumptions

The TTI research team selected the following 7 CDBs from the previous HGB 2008 ozone standard RFP EIs project emission rate runs with different analysis years, different control strategies, different counties to perform inventory mode runs with generator database output selected in MOVES3 advanced features.

- mvs31_rfp08stdh_2011cs2_48071_er_cdb_in
- mvs31_rfp08stdh_2017cs0_48039_er_cdb_in
- mvs31_rfp08stdh_2018cs1_48039_er_cdb_in
- mvs31_rfp08stdh_2020cs3_48039_er_cdb_in
- mvs31_rfp08stdh_2023cs0_48071_er_cdb_in
- mvs31_rfp08stdh_2026cs1_48039_er_cdb_in
- mvs31_rfp08stdh_2027cs2_48071_er_cdb_in

3.2.2 Processing

The operating mode ratios or fractions were based on the MOVES advanced features generator output “operatingmodedistribution” table extracted (into tab-delimited text files) from the HGB RFP runs described previously (see Table 18).

The operating mode distributions (fractions) were extracted for linkID “1” (off-network). The pertinent fields extracted are:

- sourceTypeID,
- hourDayID,
- linkID,
- polProcessID,
- opModelID,
- opModeFraction.

From the HGB RFP run output data, the following observations and conclusions were drawn:

- All on-network links only have operating mode 300 (All running). Cold soak emissions only happen on off-network links.
- For processes 11 (permeation), 12 (tank vapor venting), and 13 (liquid leaks), cold soak activity has identical distributions on off-network links.
- For different FIPS codes (counties) and different analysis years, the operating mode distribution of each source type in each hour is almost identical (at least rounding to 5 digits). This means in the HGB area modeling, one set of operating mode distributions will be applied to all scenarios.
- The operating mode distribution is changing by the hour of the day for all MOVES source types. Using a passenger car as an example, Figure 3 shows the comparison between the hourly cold soak operating mode distribution and daily average operating mode cold soak fraction on off-network links. The passenger cars have higher cold soaking fractions overnight, while the lowest fractions happen during PM peak hours. Similar trends are observed among all MOVES source types and the trend is reasonable since vehicles are more possibly moving on on-network links or hot soaking on off-network links during daytime in general.

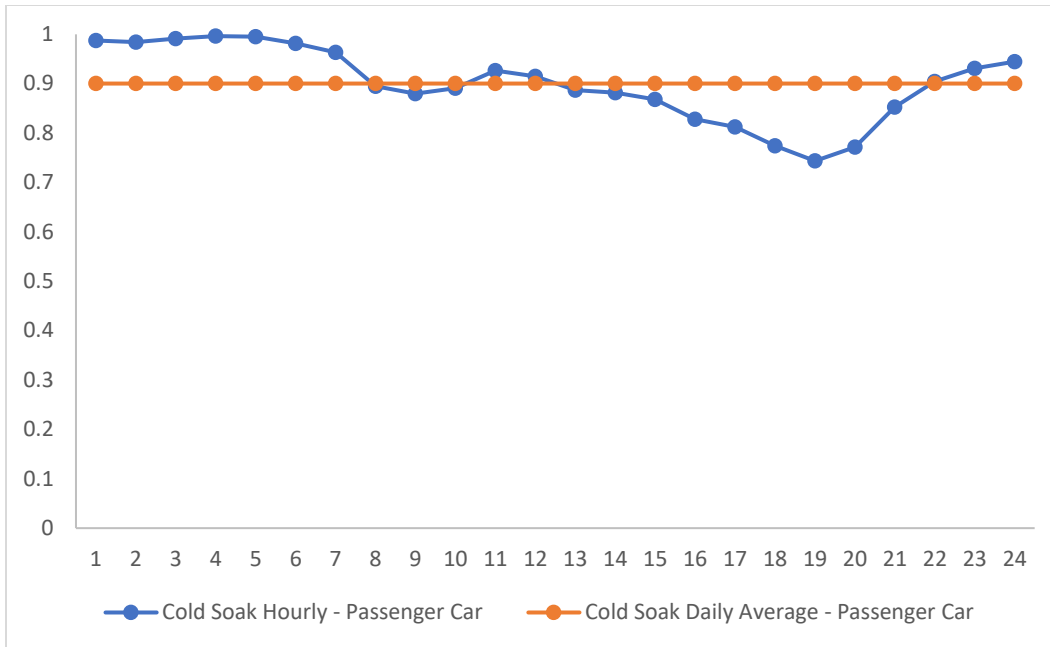


Figure 3. Cold Soaking Hourly vs. Daily Average Operating Mode Distribution on Off-network Links for Passenger Cars in HGB Area

Minimal processing was required to prepare the operating mode fractions for use in Method 2. Extracted operating mode fraction tables from the MOVES output were processed in a spreadsheet in preparation for input (in excel workbook format as provided in Appendix A) to the Python based emission ratio calculations. Since the operating mode fractions were the same for all test runs, one set of hourly operating mode fractions for each process (identified by polprocessID 111 [total gaseous hydrocarbon/permeation and 113 [total gaseous hydrocarbons/liquid leaks]) was prepared for input to the opmode emissions ratio calculations for permeation and liquid leaks for all the counties in the HGB area.

3.3 DEVELOPMENT OF OPERATING MODE EMISSION RATE RATIOS

In the second major step of the process, the emissions rate ratios were developed for each of the three operating modes. A separate set was developed for the permeation process and for the liquid leak process.

3.3.1 Permeation

3.3.1.1 Inputs, Assumptions, and Key Formula

As it is illustrated in Section 2, MOVES does not provide operating mode based evaporative permeation emission rates. In the MOVES technical documentation, Equation 1 in Section 2 (derived from the E-65 permeation study) is applied in the MOVES model to calculate the adjustment for the tank temperatures to the base permeation rate. In addition to that, the ethanol impact on evaporative emissions has been applied as a fuel adjustment (f_{adj}) in to the calculation besides the tank temperature adjustment as Equation 9:

$$P_{adj}' = P_{adj} \times f_{adj} \quad (9)$$

The evaporative permeation rates ratio for operating mode i , in hour h is then calculated as the evaporative permeation emission rate for operating mode i and hour h divided by the sum of the rates of all three evaporative operating modes. For each MOVES source type, it is assumed that the fuel adjustment and the base rate is the same for all three evaporative operating modes, so they cancel out in the rates ratio calculation as Equation 10:

$$R_{er,i,per,h} = \frac{P_{adj,i,per,h}'}{\sum_i P_{adj,i,per,h}'} = \frac{P_{adj,i,per,h}}{\sum_i P_{adj,i,per,h}} = \frac{e^{0.0385(T_{i,h}-T_{base,h})}}{\sum_i e^{0.0385(T_{i,h}-T_{base,h})}} \quad (10)$$

Where:

$R_{er,i,per,h}$ = Ratio of evaporative emission rates to total evaporative emission rates in evaporative permeation (per in equation), of operating mode, i , hour h .

$P_{adj,i,p,h}'$ = evaporative emission rate of operating mode i , hour h .

$P_{adj,i,p,h}$ = evaporative emission rate of operating mode i , hour h before fuel adjustment.

$T_{i,h}$ = Tank Temperature in operating mode i , hour h .

$T_{base,h}$ = Base Temperature for a given cycle (72F in test data applied by MOVES).

The tank temperatures of evaporative operating modes were based on the MOVES advanced features generator output "averagetanktemperature" table extracted (into tab-delimited text files) from the HGB RFP runs described previously (see Table 18).

3.3.1.2 Processing

The average tank temperatures for evaporative operating modes were extracted for linkID "1" (off-network). The pertinent fields extracted are:

- tankTemperatureGroupID,
- zoneID,
- monthID,
- hourDayID,
- opModelID,
- averageTankTemperature,
- averageTankTemperatureCV.

From the HGB RFP run output data, the following observations and conclusions were drawn:

- For different FIPS codes (counties) and different analysis years, the tank temperatures are identical in all combinations (at least rounding to 5 digits). It means in the HGB area, one set of tank temperatures will be applied to all scenarios.
- The tank temperature in all operating modes varies by different hours of the day.
- For cold soaking activities, tank temperatures are the same for all MOVES sourcetypes.
- The tank temperature group ID mapping table is required to map tank temperatures to MOVES sourcetypes.

The tank temperature group ID mapping table (Table 20) was based on the MOVES default database “tanktemperaturegroup” table. With the mapping table, the tank temperatures are mapped to MOVES source types, model years (age distribution), hours of the day, and evaporative operating modes. Using Equation 10 and the specified inputs (in excel workbook format as provided in Appendix A), the evaporative permeation rates ratios by operating mode, MOVES source type, mode year, and hour of the day were calculated as intermediate results with Python scripts developed by TTI researchers.

Table 20. Tank Temperature Group ID to Source Type ID and Model Year Mapping.

Tank Temperature GroupID	Tank Temperature Group Name	SourceTypeID	FirstModelYear	LastModelYear
1	Motorcycles (11)	11	1960	2060
2	Pre-1996 PassengerTrucks(31)	31	1960	1995
3	1996 and later Passenger Cars (21)	21	1996	2060
4	pre-1996 Light Commercial Trucks (32)	32	1960	1995
41	Intercity Bus (41)	41	1960	2060
42	Transit Bus (42)	42	1960	2060
43	School Bus (43)	43	1960	2060
51	Refuse Truck (51)	51	1960	2060
52	Single Unit Short Haul Truck (52)	52	1960	2060
53	Single Unit Long Haul Truck (53)	53	1960	2060
54	Motor Home (54)	54	1960	2060
61	Short Haul Combination Truck (61)	61	1960	2060
62	Long Haul Combination Truck (62)	62	1960	2060
5	Pre-1996 Passenger Cars (21)	21	1960	1995
31	1996 and later Passenger Trucks (31)	31	1996	2060
32	1996-and-later Light Commercial Trucks (32)	32	1996	2060

3.3.2 Liquid Leaks

3.3.2.1 Inputs and Assumptions and Key Formula

In MOVES, evaporative liquid leak emissions quantify any non-vapor fuel loss from the fuel system. Table 14 and Table 15 lists the operating mode based fleet weighted liquid leak rate for non-Tier 3 vehicles and Tier 3 vehicles.

It is assumed in this study that the emission rates for evaporative liquid leaks in the HGB area are the same as the MOVES default values, which are 24-hour averages. Equation 11 shows the rates ratio calculations for evaporative liquid leak emissions:

$$R_{er,i,leak} = \frac{L_{MOVES,i,leak}}{\sum_i L_{MOVES,i,leak}} \quad (11)$$

Where:

$R_{er,i,leak}$ = Ratio of evaporative emission rates to total evaporative emission rates in evaporative liquid leaks (leak in equation), of operating mode i.

$L_{MOVES,i,leak}$ = evaporative liquid leak emission rates of operating mode i in MOVES technical document.

3.3.2.2 Processing

The evaporative fuel leak rates ratios by operating mode, age group, MOVES source types (same values for all MOVES source types), and hour of the day (same values for all hours of the day) were calculated as shown in Table 21 using the emission rates, from the MOVES technical report, as previously summarized in Table 14 and Table 15. The ratios (in excel workbook format as provided in Appendix A) were inputs to the Python emission ratio calculation scripts developed by TTI researchers. Since the rates ratios are very similar between before Tier 3 and Tier 3 vehicles, only one set (before Tier 3 set) was used in the analysis.

Table 21. Evaporative Liquid Leak Emission Rate Ratios.

Regulations	Age group	Cold Soak	Hot Soak	Operating
Before Tier 3	0-9	4.89%	9.24%	85.87%
	10-14	4.78%	9.18%	86.04%
	15-19	4.75%	9.18%	86.08%
	20+	4.78%	9.19%	86.03%
Tier 3	0-9	4.90%	9.09%	86.01%
	10-14	4.77%	9.30%	85.93%
	15-19	4.73%	9.22%	86.04%
	20+	4.75%	9.19%	86.05%

3.4 DEVELOPMENT OF OPERATING MODE EMISSIONS FRACTIONS

The third major step is to conduct post-processing work on the ratio of rates and ratio of operating mode fractions to calculate the ratio of cold soak emissions to total evaporative emissions in the permeation and liquid leak evaporative processes.

3.4.1 Inputs, Assumptions, and Key Formula

The inputs for operating mode emissions fraction calculations are the operating mode distribution data calculated in Section 3.2 and emission rates fraction data calculated in Section 3.3. With Equation 6, the off-network cold soak, running, and hot soak emissions ratios were used for splitting permeation and liquid leak emissions into these three operating mode subcomponents.

3.4.2 Processing

The emission ratios are calculated at the resolution of MOVES sourcetype and hour of the day with Python scripts developed by TTI researchers. County based age distributions and scenario analysis years were used to aggregate the ratio from tank temperature groups and model year groups. The pertinent fields for emission ratios calculated are:

- sourceTypeID,
- hourDayID,
- roadTypeID,
- processID,
- Cold Soak Ratio,
- Hot Soak Ratio, and
- Running Ratio.

3.5 APPLICATION OF OPERATING MODE EMISSIONS FRACTIONS TO VMT OFFSET INVENTORIES

In this step, the HGB and DFW RFP and VMT offset EIs, as defined in Table 1, were post-processed to isolate the cold soak evaporative component of permeation and liquid leak VOC emissions, as well as to delineate the hot soak and running components with Python scripts developed by TTI researchers.

3.5.1 Inputs and Assumptions

The inputs consisted of:

- the original, standard, tab-delimited county EI summary files (72) to be post-processing, and
- the off-network permeation and liquid leak operating mode emissions fractions for splitting the off-network permeation and liquid leak process emissions into cold soak, running, and hot soak emissions subcategories.

The standard tab-delimited EI summary files (i.e., tab-file) contain county level activity and emissions (in units of pounds) by pollutant, process, TDM roadway type (including the off-network category), and vehicle type, for each hour of the day and a 24-hour summary. One header row is followed by the data rows forming the hourly and 24-hour totals data blocks (starting with midnight hour and ending with 24-hour day). The first four column headers are for the descriptive information of "Hour", "Activity/Emissions", "Units", and "Roadway Type". The descriptive information columns are followed by a column for each vehicle type (MOVES source use type and fuel type combination) containing the activity and emissions data. These files contain all of the original EI emissions and activity values, including VMT, VHT, speed (VMT/VHT), pollutant¹⁶ totals, and pollutant process totals (with the "off-network" category listed as the last road type preceding the TOTALS row in each data block, and with starts, SHP, SHEI, and APU activity rows last in the activity data block for each time period).

The off-network permeation and liquid leak operating mode emissions fractions are an internal data set calculated by the Python routine, as described in the previous section.

3.5.2 Processing

Each of the original 72 county EI files were processed by the Python application by matching the off-network evaporative permeation and liquid leak VOC emissions values to be post-processed with the applicable post-processing factors (e.g., by pollutant-process, hour, roadway type [i.e., off-network], and each gasoline powered source type). The operating mode emissions fractions were applied to essentially split each original row into three rows, for each of the two emission processes. All of the original EI data were written to the newly post-processed output file, except for the original rows post-

¹⁶ The following eight pollutants were modeled: volatile organic compounds (VOC), oxides of nitrogen (NO_x), carbon monoxide (CO), ammonia (NH₃), sulfur dioxide (SO₂), atmospheric carbon dioxide (CO₂), and particulate matter (PM) pollutants in both 2.5 and 10-micron size categories (PM_{2.5} and PM₁₀).

processed, which were replaced in each time period of the output file with the six new rows, labeled "VOC Evap_Fuel_Leak_ColdSoak", "VOC Evap_Fuel_Leak_HotSoak", "VOC Evap_Fuel_Leak_Running", "VOC Evap_Permeation_ColdSoak", "VOC Evap_Permeation_HotSoak", "VOC Evap_Permeation_Running" in the "Activity/Emissions" column, corresponding to "Off-Network" in the "Roadway Type" column.

From these post-processed county EI files, the VOC emissions were extracted, excluding the off-network permeation and off-network liquid leak cold soak VOC emissions and summarized by county and at the area level.

4.0 CONCLUSIONS AND FUTURE RESEARCH

In this project, TTI researchers developed, assessed, and applied a methodology to calculate VOC evaporative emissions by sub-process operating modes. In the context of the VMT offset EI analyses, the methodology provided a conservative estimate by excluding cold soak evaporative emissions, which are unrelated to VMT and trips, only from total evaporative permeation and liquid leak HGB and DFW area VMT offset demonstration EIs.

The results from this project show the capability to isolate and quantify EI components dependent on different activity input parameters by using MOVES3 information. These updated EI outputs would help support the DFW and HGB SIP revision for the 2008 eight-hour ozone NAAQS.

Due to the complexity of the MOVES tank vapor venting emissions process algorithms and lack of identifiably usable information in the MOVES advanced features generator output, and time constraints, only permeation and fuel leaks process emissions were post-processed into operating mode components for this project. Recommended future research is the continuation of work on developing procedures for separating tank vapor venting emissions into operating modes, with guidance from EPA, to enable the complete quantification of off-network evaporative process emissions by operating mode component, i.e., in all three on-road evaporative emission processes.

5.0 QUALITY ASSURANCE

Analyses and results were subjected to appropriate internal review and quality assurance (QA)/quality control (QC) procedures, including independent verification and reasonableness checks. All work was completed consistent with applicable elements of the American Society for Quality, American National Standard (ASQ/ANSI): E4:2014: *Quality Management Systems for Environmental Information and Technology Programs – Requirements with Guidance for Use*, February 2014, and the TCEQ Quality Management Plan.

The Quality Assurance Project Plans (QAPP) category and project type most closely matching the intended use of this analysis are QAPP Category Level III - Research Model Development and Application Projects. The internal review and quality control measures utilized were consistent with requirements specified in the EPA QA/R-5, EPA Requirements for Quality Assurance Project Plans, and in the Research Model Development or Application category¹⁷. The required audits of data quality (i.e., a minimum of 10%) and reporting of findings were performed.

5.1 PROJECT MANAGEMENT

The definition and background of the problem addressed by this project, the project/task description, and project documents and records produced were as described previously in the Purpose and Background sections of the Grant Activity Description (GAD). No special training or certifications were required. The TTI project manager assured that the appropriate project personnel had and used the most current, approved version of the QAPP.

The objective was to develop a methodology and produce the emissions inventory products of the quality suited to their purpose as specified in the Purpose and Background section of this GAD informed by, and consistent with, the appropriate guidance and methods provided in the references in this GAD, and in consultation with the TCEQ PM.

Basic criteria were used to assure that the acceptable quality of the product was met – research staff verified that the processes and products were as stated previously, including:

¹⁷ PDF available at:

<https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/qa/ResearchModelDevandAppQAPPNRMRL.pdf>

- a. The product meets the purpose of the emissions analysis (i.e., develop a methodology and produce emissions inventories required to support the HGB and DFW area VMT offset associated with respective RFPs);
- b. The full extent of the modeling domain is included (i.e., analysis years, geographic coverage, seasonal periods, sources, pollutants);
- c. Agreed methods, models, tools, and data are used;
- d. The required output data sets are produced in the appropriate formats;
- e. Any deficiencies found during development and end-product quality checks are corrected (as discussed following sections); and
- f. Aggregate emissions.

5.2 MEASUREMENT AND DATA ACQUISITION

Note that no sampling of data was involved in the EI development; thus, only existing data (non-direct measurements) were used for this project.

The data needed for project implementation were in the categories needed for the development of methodology, applying the methodology to estimate the appropriate emissions rate for emissions calculations. TTI developed the emissions factor and activity inputs using data sources as outlined previously and/or methods and procedures detailed in the references section.

All data used as direct input or to produce inputs were reviewed by TTI for suitability before use. The data sets for the project were provided by cognizant organizations or agencies and have been formally adopted by the providing agency.

5.3 DATA MANAGEMENT

TTI emissions inventory data developers work as a team. The assigned staff used the same electronic project folder structure on their workstations. As various scripts, inputs, and outputs were developed in the emissions inventory production process, data were shared within the team for crosschecking via an intranet, flash drive, or external hard drive. After input data were QA'd, depending on the size of the data set, the data sets were backed up and stored in compressed files along with the QA record/s. These activities were performed throughout the process until the final products were produced.

After the final product was completed, all of the project data archives were compiled on a USB flash drive or on an external drive for very large project data sets. A complete archive of the project data will be kept by TTI (emissions inventory development scripts used in the process are included). An electronic data submittal package (containing the project deliverables as listed in this GAD) was produced along with a data description for delivery to TCEQ (on a USB flash or external hard drive, depending on needed storage space).

5.4 ASSESSMENT AND OVERSIGHT

The following assessments were performed.

- Verification that the overall scope is met (consistent with the intended purpose, for specified temporal resolution and geographic coverage, for specified sources, pollutants, and emissions processes);
- Checks on input data preparation and structured query language (SQL) execution scripts (e.g., activity data, model inputs, SQL scripts, etc.); and
- Checks on output data produced (includes interim output [output that becomes an input to a subsequent step in the inventory development process], as well as the final product). Records are kept of the checks performed.

Where inconsistencies or deficiencies were found, the issue was directly communicated to the responsible staff for correction (or the outside agency staff involved, if provided from outside of TTI, if needed). After a correction was made, the QA checks were performed again to ensure that the additional work resulted in the intended quality assured result, and the correction was noted in the QA record (the process was performed until the QA check was satisfied).

Any major problem was reported to the PM and communicated to the project team as needed, as well as when the various data elements in the process passed QA checks and were ready for further processing according. The TTI PI ensured that all of the QA checks performed were compiled and maintained in the project archives. In addition, any errors or issues identified by TCEQ staff, independent of the QA/QC steps taken by TTI, were addressed by TTI based on direction from the TCEQ PM.

In addition, technical systems audits were performed as appropriate. Audits of data quality at the requisite 25 percent level were performed for any data produced as part of

this study. QA findings were reported in both the draft and the final reports. Specific checks to be performed were listed in Section 5.5.

5.5 DATA VALIDATION AND USABILITY

Erroneous or improper inputs at any point during the methodology and emissions inventory development process may produce resulting emissions estimates that are inaccurate and may not be suitable for their intended purpose. Adherence to the inventory process flow with the performance of the integrated QA checks at each step of the process is of the utmost importance to ensure that the results meet the project objectives. Therefore, the QA checks listed in Section 5.4 were performed until satisfied to ensure that the resulting emissions inventories meet TCEQ's requirements of intended use.

As previously stated, TTI verified the overall scope of the emissions analysis to include the following.

- Purpose of the emissions analysis;
- The extent of the modeling domain (e.g., analysis years, geographic coverage, seasonal periods, sources, pollutants);
- Methods, models, and data used (e.g., default versus local input data sources); and
- Procedures and tools used, and all required emissions output data sets are produced.

TTI performed checks on input data, model execution, and output, as follows.

- Input data preparation checks:
 - Verify the basis of input data sets against the PGA and GAD: Actual historical or latest available data, validated model, expected values or regulated limits, regulatory program design, model defaults, surrogates, professional judgment; check aggregation levels;
 - Data development: Depending on the procedure and input data set, calculations may be verified (e.g., re-calculated independently and compared with originally prepared values – if spot-checking a series of results, including extremes and intermediate values);
 - Completeness: Verify that input data sets are within the required dimensions, and all required fields are populated and properly coded or labeled;

- Format: Verify that formats are within required specifications if any (e.g., field positions, data types and formats, and file formats);
- Reasonability checks: (discussed later); and
- Ensure that any inputs provided from external sources are quality assured, as listed previously.
- Checks on model execution instructions:
 - Verify that the correct specifications are prepared for each analysis in the inputs (e.g., by year, season); and
 - Verify that each SQL script includes the correct specifications for the application (e.g., commands, input values, input and output file paths, output options).
 - Check for the successful completion of model executions:
 - Verify that the correct number of each type of output file was produced by the model;
 - Check for any unusual output file sizes;
 - Search output for warnings and errors (e.g., model execution logs that contain error and warning records); and
 - Check the summary information provided in the output files for any unusual results.

TTI performed further checks for consistency, completeness, and reasonability of data output from model or utility applications.

- Verify that fleet mix distribution factors produced or used sum to 1.0, as appropriate;
- Verify that the required data fields are present, populated, and properly coded or labeled; verify that data and file formats are within specifications;
- Verify that any activity and emissions adjustments were performed as intended (e.g., seasonal activity factor, emissions control program adjustment);
- Verify if the hierarchy is applied appropriately (i.e., local data are preferred and used versus other data sets).
- Check for consistency between data sets (e.g., compare detailed disaggregated activity estimates with aggregate totals available from other sources);
- Compare the final emissions and activity data for the outliers while assessing the reasonability of any relative and directional differences (e.g., qualify based on activity distributions and fleet mix and control program coverage);

- Verify the emissions and activity trends by plotting graphs and checking for any inconsistencies; and
- Compare the results to results from previous analyses, where available.

Any additional data products required for the emissions analysis were subjected to the appropriate previously listed QA checks.

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APPENDIX A: HGB VOS ON-ROAD INVENTORIES ELECTRONIC DATA SUBMITTAL (ELECTRONIC ONLY)

This appendix is available separately in an electronic format (e.g., .docx, .xlsx, .pdf, .txt, .zip, or other format.) and can be provided upon request.